Quantum Physics

1. **Course number and name:** 020PHQCI4 Quantum Physics

2. **Credits and contact hours:** 2 ECTS credits, 1x1:15 contact hours

3. **Name(s) of instructor(s) or course coordinator(s):** Rémi Ziad Daou

4. **Instructional materials :** Course handouts ; Reference : Physique MP/MP* - MPI/MPI*. Tout-en-un, J'intègre – DUNOD ($5^{ème}$ édition).

5. **Specific course information**
   a. **Catalog description:**
   This course is concerned with two aspects of modern physics. The first based on the Schrodinger formulation of the wave mechanics and is treat simple but fundamental problems: free particle, particle in a single-step potential, tunnel effect, particle in a box and energy quantification. The second is an introduction to statistical thermodynamics where macroscopic properties of a system are to be related to its microscopic constituents. The Boltzmann factor is introduced for the isothermal atmosphere model then generalized to systems with a discreet spectrum of energy. Equipartition theorem is then used to evaluate heat capacity of gases and solids.

   b. **Prerequisites:** 020EMECI3 Electromagnetism

   c. **Required/Selected Elective/Open Elective:** Required

6. **Educational objectives for the course**
   a. **Specific outcomes of instruction:**
      – Describe an example of an experiment demonstrating the need for the concept of the photon.
      – Describe an example of an experiment demonstrating the wave-like behavior of matter. Evaluate typical orders of magnitude involved in quantum phenomena.
      – Interpret a particle-by-particle interference experiment (matter or light) in probabilistic terms.
      – By analogy with the diffraction of light waves, establish the order-of-magnitude inequality: $\Delta p \, \Delta x \geq \hbar$.
      – Exploit the hypothesis of quantization of orbital angular momentum to obtain the expression for the electronic energy levels of the hydrogen atom.
      – Interpret in terms of probability the amplitude of a wave associated with a particle.
      – Use the linear nature of the equation (principle of superposition).
      – Separate the variables time and space.
      – Distinguish between a wave associated with a stationary state in quantum mechanics and a stationary wave in the usual sense of wave physics.

- Relate the energy of the particle to the time evolution of its wave function and make the link with the Planck-Einstein relation.
- Identify the term associated with kinetic energy.
- Establish the solutions.
- Interpret the difficulty of normalizing this wave function.
- Relate the energy of the particle and the wave vector of the associated plane wave.
- Cite physical examples illustrating this problem.
- Exploit the (accepted) continuity conditions relating to the wave function.
- Establish the solution for a particle incident on a potential step.
- Explain the differences in behavior compared with a conventional particle.
- Determine the transmission and reflection coefficients using probability currents. Recognize the existence of an evanescent wave and characterize it.
- Describe qualitatively the influence of the height or width of the potential barrier on the transmission coefficient.
- Use a supplied transmission coefficient. Cite applications.
- Establish the solutions and energy levels of the confined particle.
- Identify analogies with other areas of physics.
- Estimate the energy of a confined particle in its ground state for a non-rectangular well.
- Associate the analysis with Heisenberg's inequality.
- Explain that a superposition of two stationary states causes the particle's state to evolve over time.
- Superposition of two stationary states; interpret the result.
- Establish the variation of pressure with altitude assuming an isothermal atmosphere.
- Interpret the law of barometric levelling with Boltzmann's weight.
- Identify a Boltzmann factor.
- Compare kT to energy differences and estimate the consequences of a temperature variation.
- Express the probability of occupying an energy state using the normalization condition.
- Exploit a probability ratio between two states.
- Express the mean energy and energy quadratic deviation of a system as a sum of its states.
- Explain why the relative energy fluctuations decrease as the size of the system increases and relate this to the quasi-certain character of thermodynamic quantities.
- Give examples of systems that can be modelled by a two-level system.
- Determine the mean energy and heat capacity of a two-level system.
- Interpret how the mean energy changes with temperature, in particular the low and high temperature limits.
- Relate energy fluctuations to heat capacity.

- Determine the average energy of a set of particles at a given temperature, in the limit where the confinement energy is small compared to the thermal agitation energy.
- Relate the expression for the mean energy as a function of temperature to the energy equipartition theorem.
- Exploit the kT/2 contribution per square degree to the mean energy.
- Count the independent quadratic degrees of energy freedom and deduce the molar heat capacity of a system.

b. PI addressed by the course:

PI	1.3	5.1	7.1
Covered	x	x	x
Assessed	x	x	x

7. Brief list of topics to be covered

- Photon - Matter wave associated with a particle - de Broglie relation - Introduction to quantum formalism Wave function - Spatial Heisenberg inequality - Wave function ψ of a spin less particle and probability density of presence - One-dimensional Schrödinger equation in a potential V(x) - Stationary states of the Schrödinger equation (3 lectures)
- TD (3 lectures)
- Free particle - de Broglie relation - Spatial Heisenberg inequality and wave packets - Probability current density - de Schrödinger equation (1 lecture)
- TD (3 lectures)
- Stationary states of a particle in a piecewise constant potential - Potential barrier and tunnel effect - Infinite potential - Confinement energy (2 lectures)
- Non-stationary states of a particle in an infinite potential well (1 lectures)
- TD (3 lectures)
- Boltzmann factor - Isothermal atmosphere model - Boltzmann weight of an independent particle in equilibrium with a thermostat (2 lectures)
- Probability of occupation of a non-degenerate energy state by an independent particle - Mean energy and mean square deviation - Case of a system with N independent particles (2 lectures)
- TD (2 lectures)
- Mean equilibrium energy - Classical heat capacities of gases and solids - Equipartition theorem - Molar heat capacity of gases - Molar heat capacity of solids - Classical Einstein model: Dulong and Petit law (2 lectures)
- TD (2 lectures)